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THE THROW OF WATER SPRAYS

by

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Summary

This report describes the derivation of an empirical formula expressing the spray throw in terms of the nozzle pressure, the cone-angle of the spray, and rate of flow of water. Most of the data were taken from an American report describing tests made on spray-nozzles for the National Fire Protection Association. Some data were also available from tests made by the Joint Fire Research Organization.

The results indicate that the throw of a spray is as much dependent on the rate of flow and the cone angle as on the pressure. All these data referred to pressures between 50 and 150 lb/sq.in. but there is some additional evidence that the throw of sprays at pressures of 300 to 600 lb/sq.in. is much less than that given by extrapolating the data for low pressure sprays.

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Introduction

The purpose of this investigation was to determine to what extent the throw of a spray depended upon pressure, rate of flow and the cone angle of the spray and to obtain an empirical formula correlating those variables.

Origin of data

The majority of the data used in the investigation was taken from a report published by the National Fire Protection Association entitled "Studies of Fire Department Fog or Water Spray Nozzles"(1). This report describes experiments conducted for the Committee on Fire Department Equipment of the National Fire Protection Association and the International Association of Fire Chiefs at Elmira, New York. Other data were obtained from experiments conducted by the Joint Fire Research Organization on some commercial spray nozzles(2).

The American report gives photographs of various spray nozzles operating in front of a vertical background marked into 2 ft. squares. From each photograph, an estimate of spray throw could be made. The nominal cone angle of each spray was also stated as either 30°, 60° or 90° but estimates of the cone angle of the spray leaving the nozzle were also made from the photographs. The pressures were 50, 100, and 150 lb.sq.in. and the rates of flow varied between 10 and 430 g.p.m.

The defination of the sprays was not sufficiently sharp to enable a precise measurement of the cone angle and throw, and six observers selected randomly were asked to estimate throw and cone-angle from twelve typical photographs in the report so that the statistical estimate of the variation between observers could be calculated. The standard deviations between observers were subsequently found to be approximately 3 feet for spray-throw and 7° for cone-angle.

Two of these observers whose respective estimates of spray-throw and cone-angle had the least deviation from the average of the six observers then evaluated the spray throw and cone angle for the sixty-two photographs available in the National Fire Protection Association report(1).

Results of analysis

(1) Data from National Fire Protection Association report(1).

From a conventional regression analysis of the estimates of throw and cone angle and the stated values of pressure and rate of flow made by one observer, the following formula was obtained.

$$t = -0{\cdot}36 + 0{\cdot}85r \quad -2{\cdot}09a + 0{\cdot}36p + 1{\cdot}03\ ra \qquad \ldots\ldots (1)$$

where small letters denote the logarithms to base 10 of the quantities

T = throw in feet

R = rate in imperial gal/min

$A = \text{Tan.}\ \frac{(\text{Total cone angle})}{4}$

$P = \frac{\text{Pressure lb/sq.in.}}{100}$

Thus t = Log T. etc.

The choice of a measure of cone angle used in the analysis was governed by the consideration that a zero cone angle would give the largest possible throw and a cone angle of 360° the least possible. By taking the tangent of $\frac{1}{4}$ of the total cone angle the upper and lower limits of A become OO and O and therefore the range of 'a' became OO to +OO and this would tend to avoid a sheer distribution. Similarly the logarithm of the lower limit of pressure and rate become -OO

The residual variance of t, as calculated above is 0·013 giving a standard deviation of 0·114. This corresponds to a factor of 1·30 on T for a typical throw of 20 ft. or to a variation of 6 ft. This appears to be significantly larger than the standard deviation between the six observers even if allowance is made for the error in reading the cone angle. The variation between the throw of the various sprays is therefore not wholly accounted for by the errors in measurement and the parameters chosen as independent variables.

Although the interaction term (1·03 r.a) was found to be significant leaving this term out does not markedly increase the residual variance of 't'. The best formula without this interaction is

$$t = 0{\cdot}396 + 0{\cdot}36\, r - 0{\cdot}57a + 0{\cdot}28p \qquad \ldots\ldots (2)$$

and the residual variance of 't' is increased to 0·015.

(2) Data from Joint Fire Research Organisation report [2].

Although only seven test results were available and these were all for one pressure, a regression analysis was made as for the other data except that throw was estimated from water distribution diagrams. The formula was obtained as

$$t = 0{\cdot}34 + 0{\cdot}55\, r - 0{\cdot}39\, a \qquad \ldots\ldots (3)$$

The data included two hollow sprays but this factor was not found significant. Giving to the large variation the cone angle term was barely significant but has been included nevertheless.

<u>Discussion</u>

If equations (2) and (3) are compared it is seen that the numerical values of the indices on rate and cone angle are different. These differences however are not significant and the two sets of data can be regarded as one combined set. Since the values of pressure incorporated in equation (2) are not significantly correlated with those of rate or cone angle it is possible to combine the two sets of data by combining equations (2) or (3). The resulting equation is

$$t = 0{\cdot}34 + 0{\cdot}37\, r - 0{\cdot}54a + 0{\cdot}28p$$

The residual variance of 't' is 0·015.

This differs little from equation (2) because that equation incorporates nearly 10 times more data than does equation (3).

The results show that the rate and the cone angle are as important as the pressure in determining the throw. If, for example the pressure is doubled, the throw according to equation (1), is increased by a factor of 1·3. The effect of rate depends on the cone angle and if this is taken as 90° the throw is increased by 1·37 when the rate is doubled under the same conditions, while if the cone angle is 60° the increase of throw is by a factor of 1·21. On the other hand at a rate of 20 gal/min. a decrease of cone angle from 90° to 60° increases the throw by a factor of 1·43.

If, as might be expected the spray momentum were a determining factor we would expect the index of nozzle pressure to be half that of the rate of flow. For simplicity this has been studied by means of equation (2) from which it may be deducted that the difference between half of 0·36 i.e. 0·18 and 0·28 is not significant in view of the error associated with each index.

Table 1

Differences between calculated and measured values of throw for some high pressure sprays.

Pressure (lb/sq.in.)	Cone angle	Rate (g.p.m.)	Throw (feet)	
			Calculated from eqn(1)	Measured from photographs
300	68°	120	31	20
300	56°	15.8	20	6
600	53°	21.3	29	9
600	27°	9.75	58	12

There are few data for sprays at pressures in excess of 150 lb sq.in. but some photographs of such sprays are given in a report of the National Board of Fire Underwriters (3) and these have been considered in relation to the above formula.

High Pressure sprays

Visual estimates of the throw from photographs of some high pressure sprays (3) have been made as for the other data and have been compared with the values calculated from equation (1) (see Table 1). This has shown that at higher pressures, the equation overestimates the throw by a large amount so the effect of pressure is in fact less than indicated by the formula where it is extrapolated to higher pressures.

Conclusion

The analysis of data based on over 60 spray conditions shows that the throw of a spray is increased by increasing the rate and the pressure and by decreasing the cone angle. The quantitative estimates of these effect show that all three factors are of comparable importance. The evidence supports the view that the energy available at the nozzle rather than the momentum of the spray determines the throw of a spray of given cone angle. The effect of pressure determined from the analysis which is confined to pressures below 150 lb/sq.in. diminishes with increasing pressure.

References

(1) "Studies of Fire Department Fog Nozzles" National Fire Protection Association 1952.

(2) Fry, J. F. "An examination of some commercially produced spray nozzles for fire fighting" Joint Fire Research Organization F.P.E. Note 39/1950.

(3) "Characteristics of water spray nozzles including those designated as Fog Nozzles for fire fighting use" National Board of Fire Underwriters (1944).

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